Effect of the Pu α–β–γ Phase Transitions on Storage Can Integrity

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Goals

- Experimentally measure the strain on a 3013-type storage can accompanying the expansion of Pu as it is heated through the α–β and β–γ phase transition temperatures.
- Model these effects using finite element analysis (SRS).
- Support changes to DOE Std 3013 for storage of Pu metal based on technically defensible data.

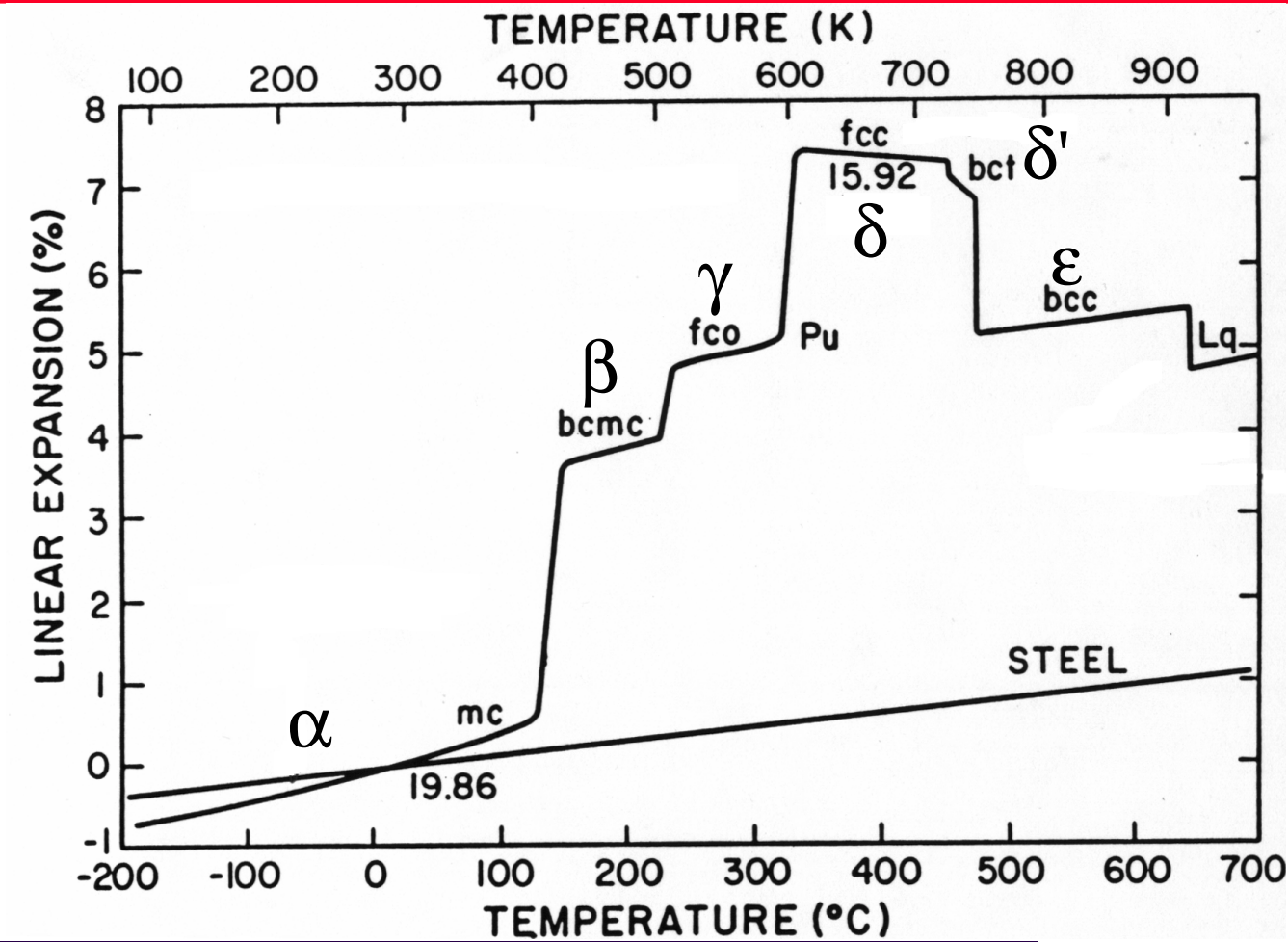
Problems

- Self-heating in insulated or non-cooled conditions could result in T > 200°C (above the α–β and β–γ transition temperatures).
- Unconstrained linear expansion of Pu:

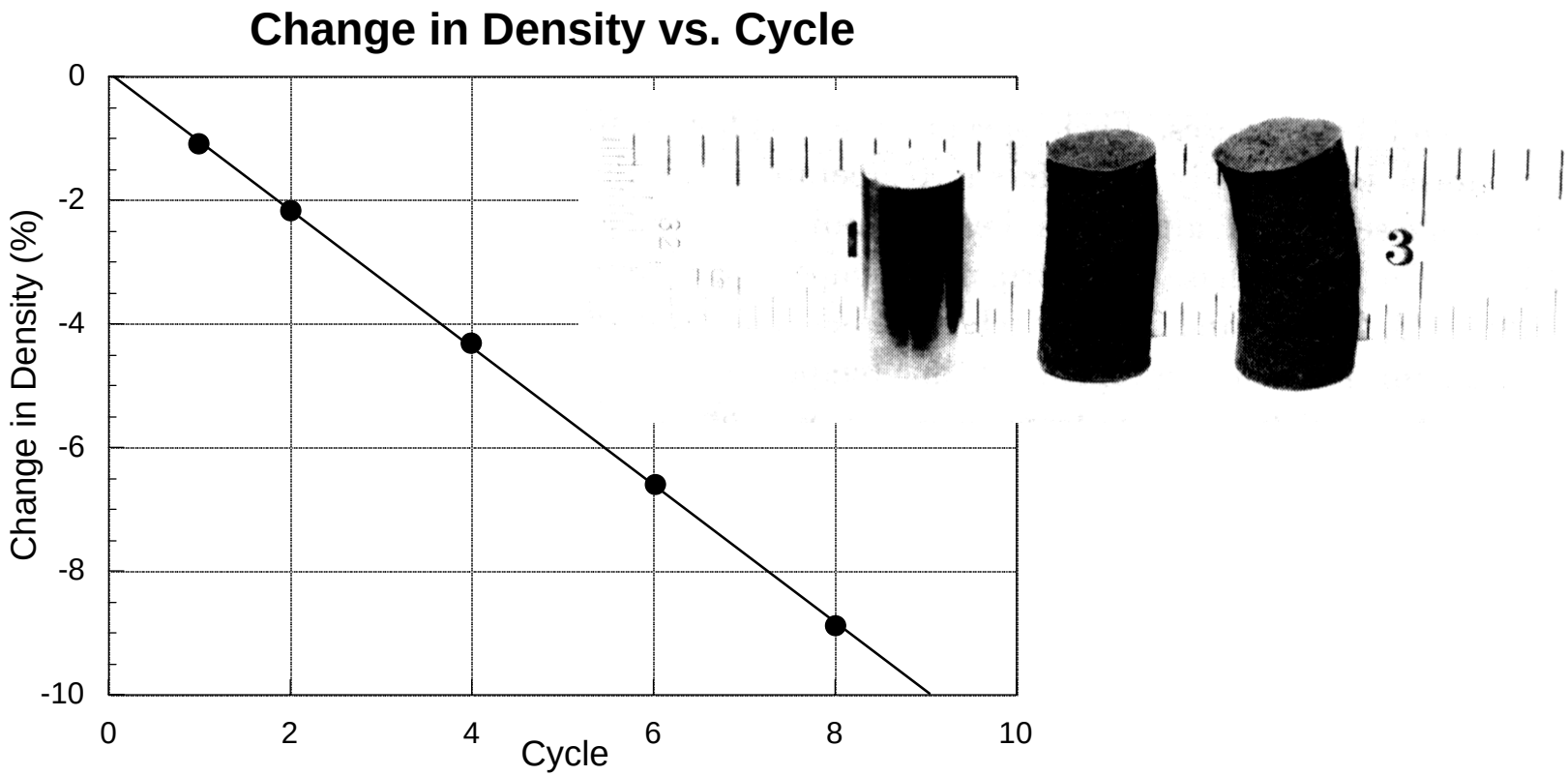
  α–β Pu: $\Delta L = 3.5\%$

  β–γ Pu: $\Delta L = 1.1\%$
- Growth of Pu metal after cycling through the α–β phase transition.
- Constrained expansion behavior of Pu has not been well established.

Pu Expansion Behavior



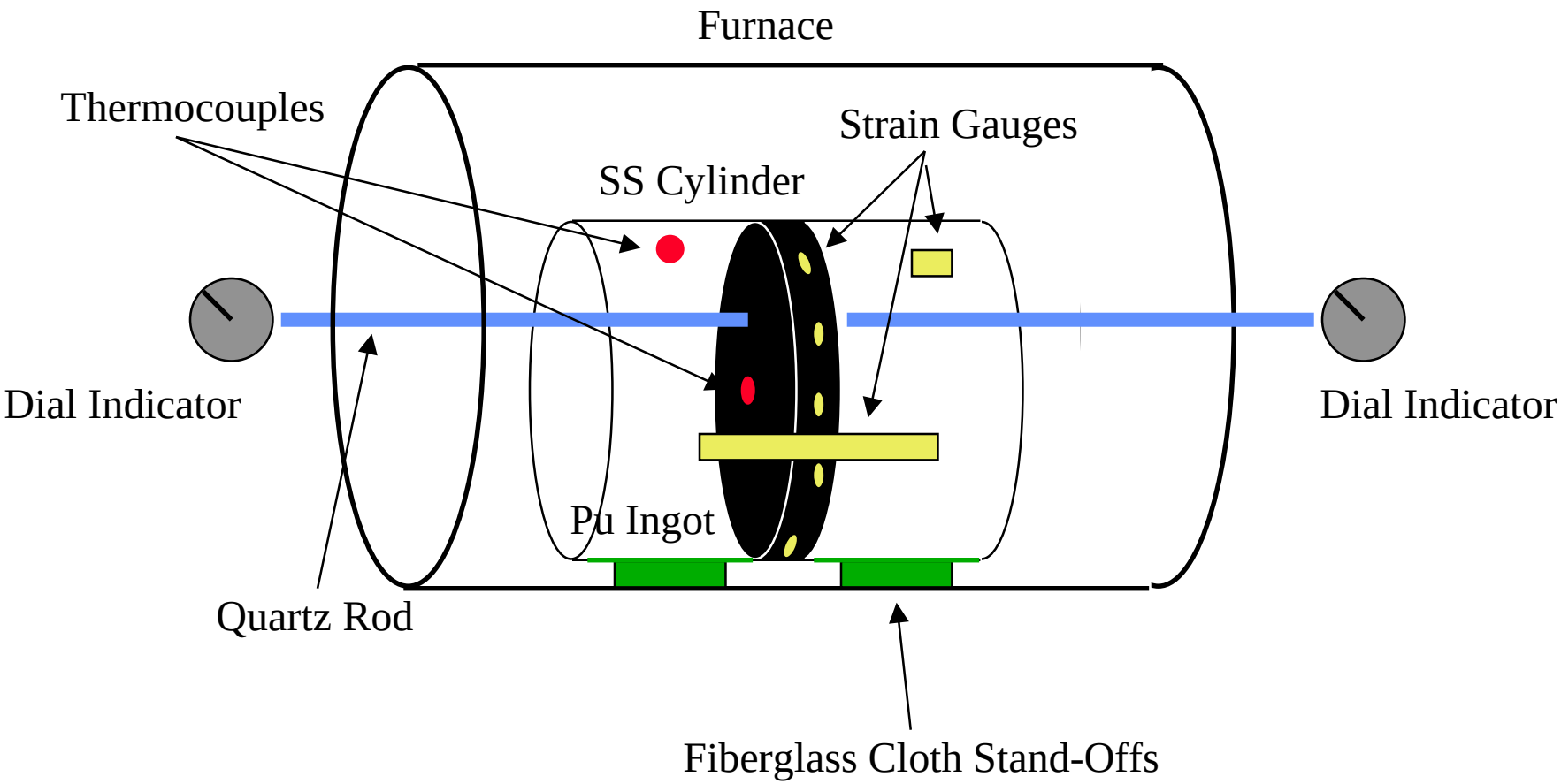
Pu Expansion Behavior



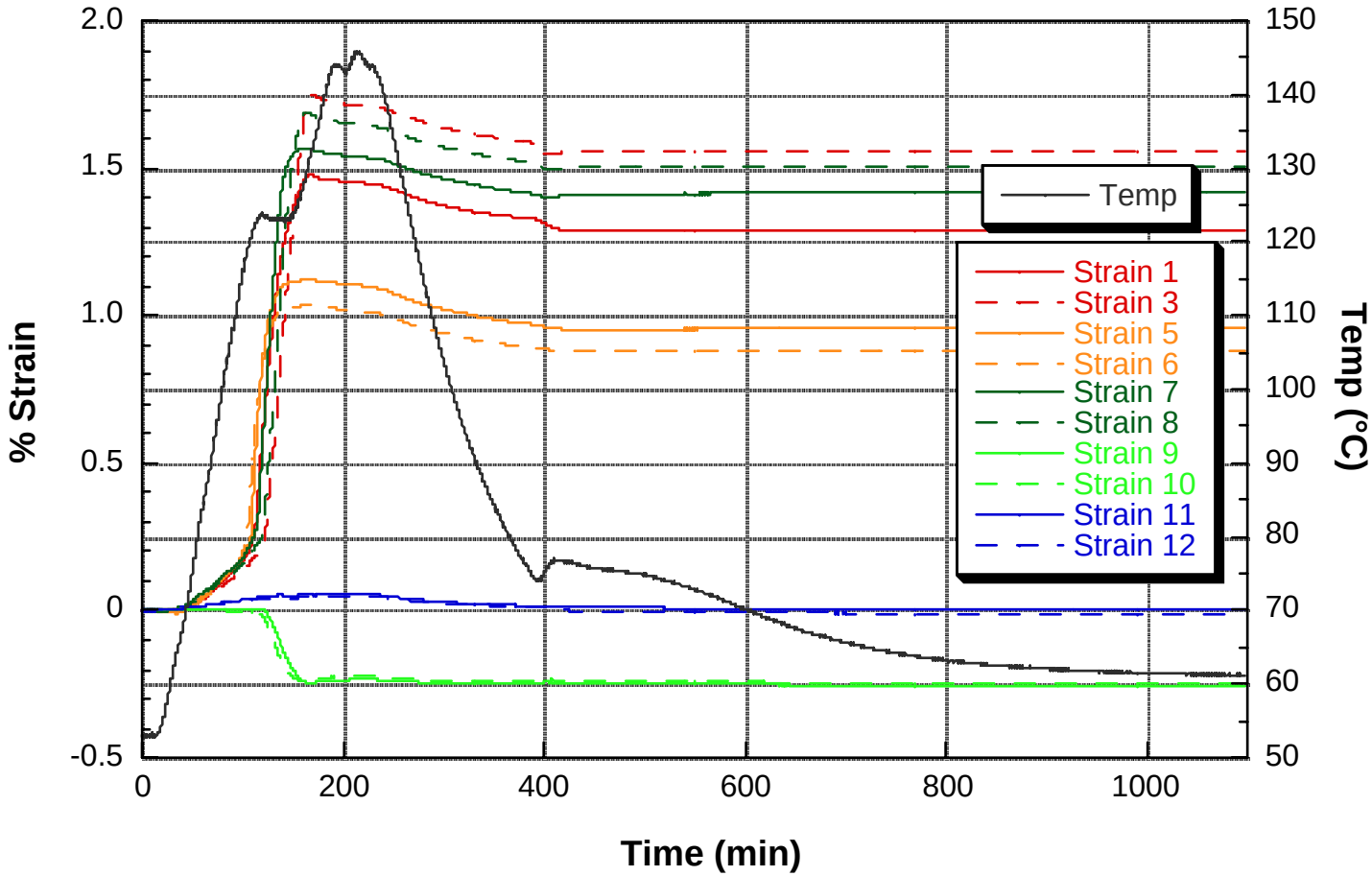
α–β Experimental Setup

- Annealed 316-SS cylinder (6” long x 4.3” ID x 0.06” thick) designed and fabricated to simulate the physical properties of a BNFL inner storage container.
- Cylindrical geometry used to facilitate FEA modeling of results.
- 3.6 kg Pu ingot:
  - Diameter 0.004” < ID of can (near zero-tolerance fit)
  - 0.75” thick
  - ρ = 19.57 g/cc (ρ_{max} = 19.87 g/cc)
- 6 hoop, 2 far-field, 2 longitudinal strain gauges, 4 thermocouples
- Quartz rod dilatometry (0.001” resolution)
- Resistively heated in tube furnace in Ar-atmosphere.

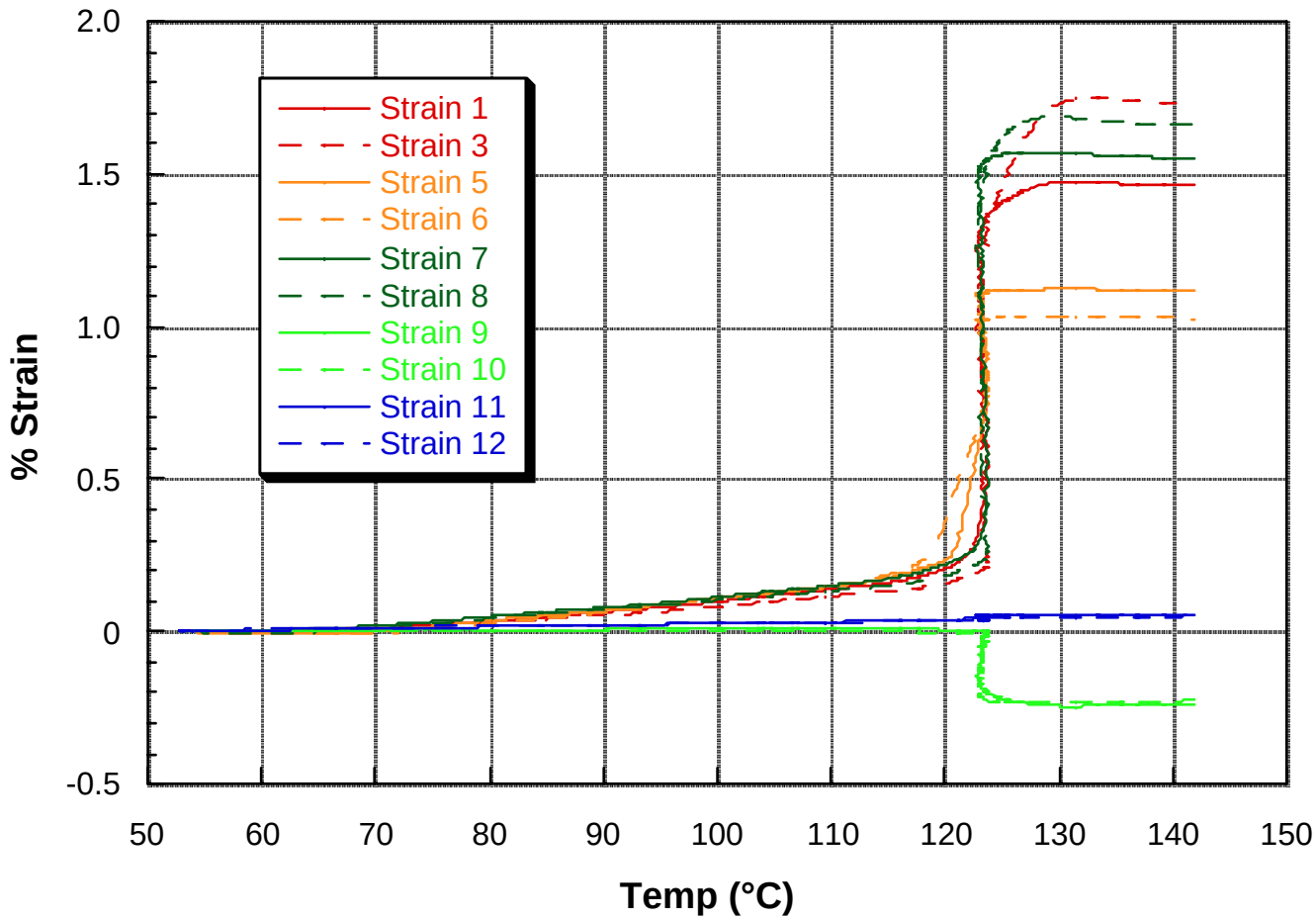
Experimental Setup



Strain/Temp vs Time (1st Cycle)



Strain vs Temp (1st Cycle)



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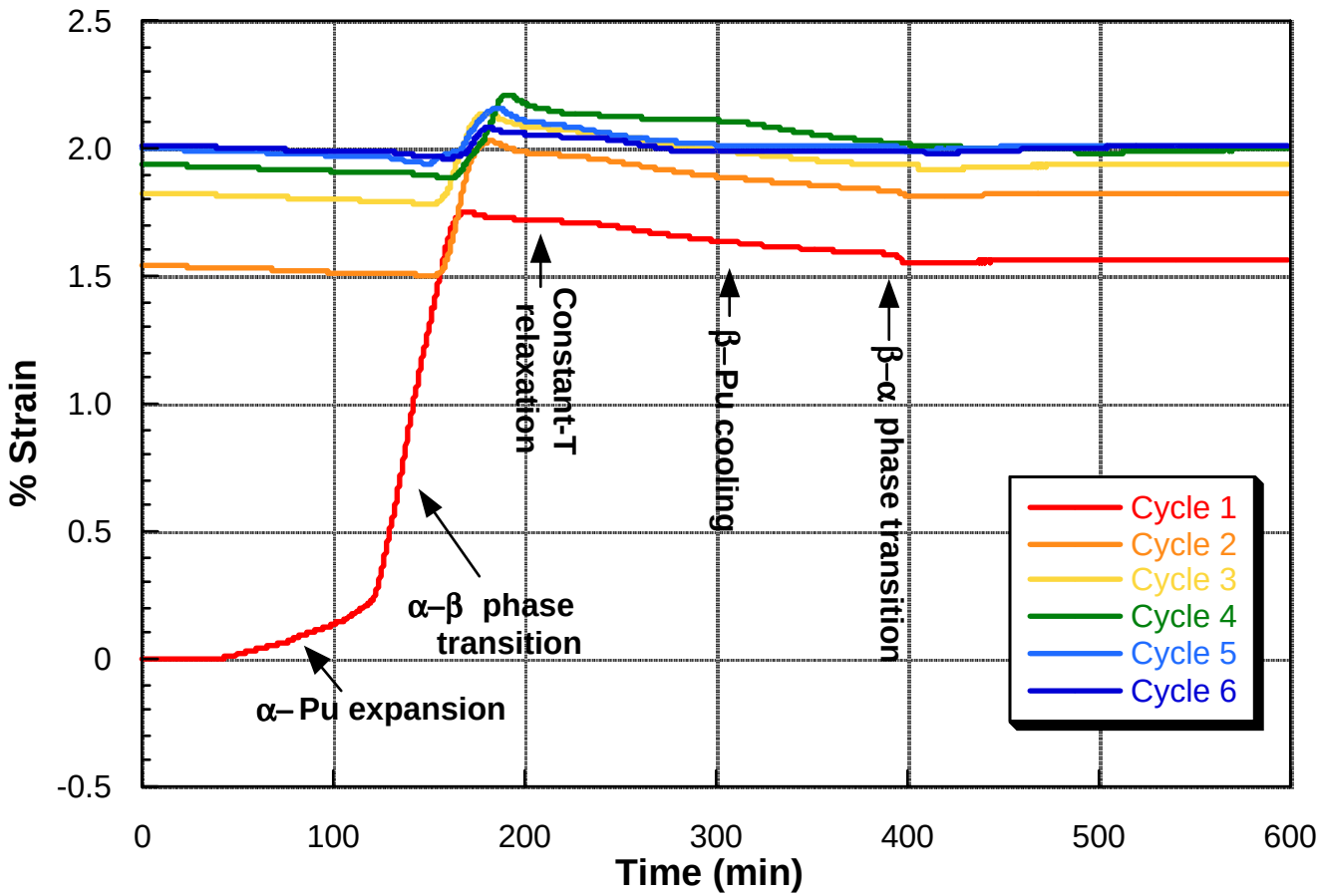
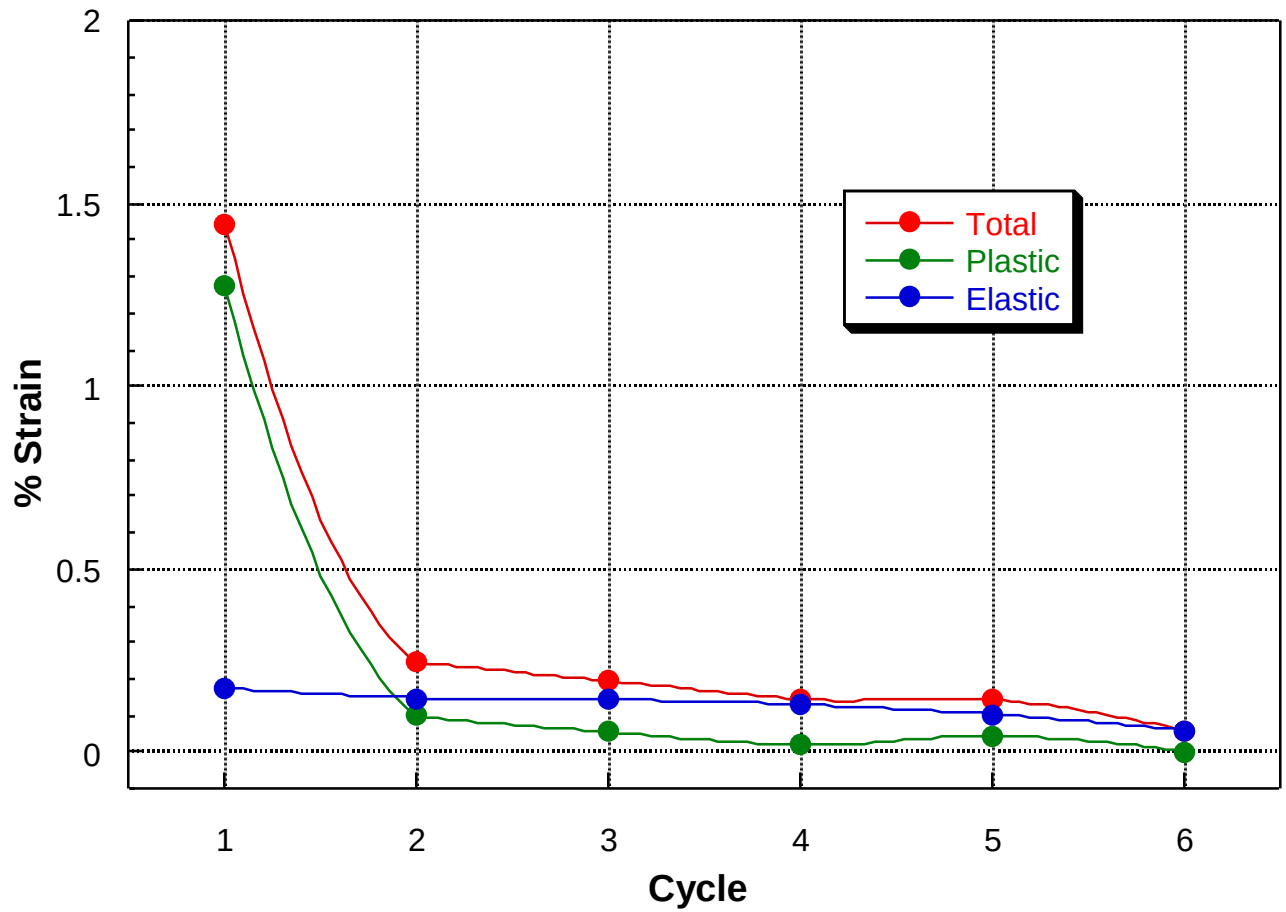
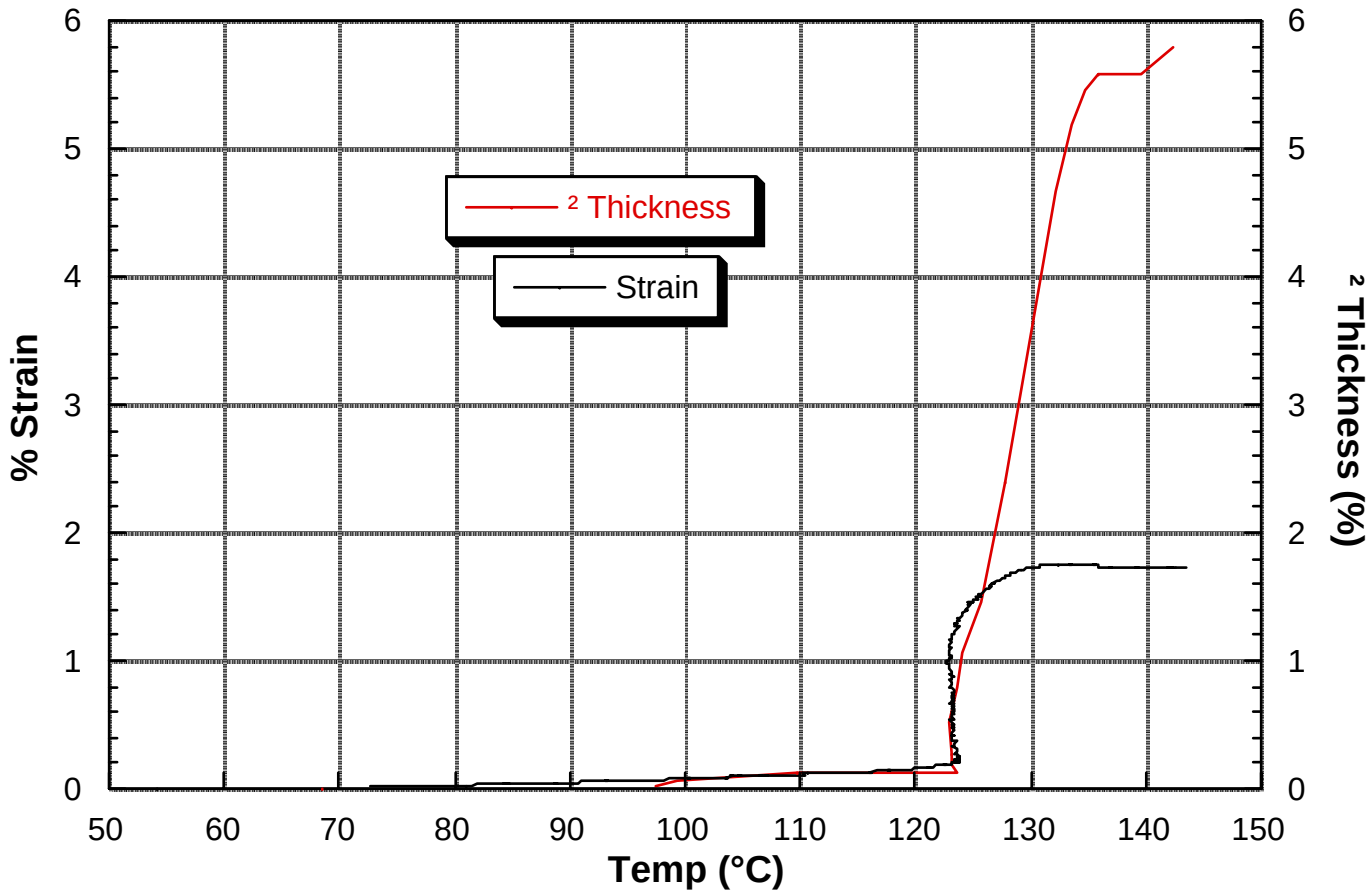
Strain vs Time



Ave. Strain vs Cycle



Strain/Thickness vs Temp (1st Cycle)



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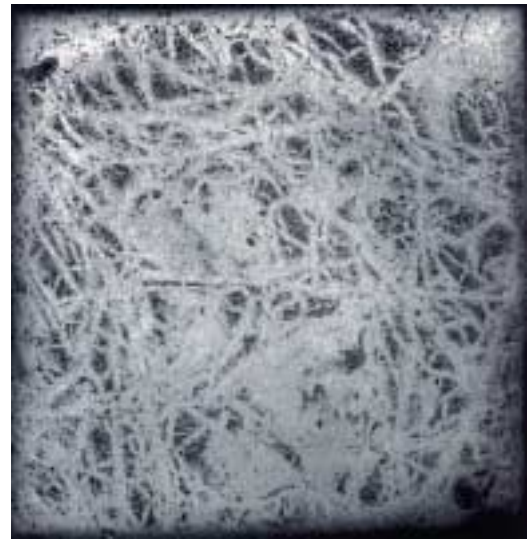
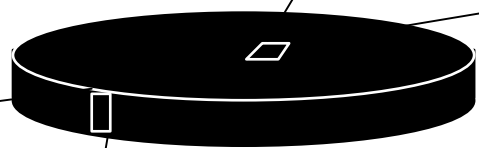
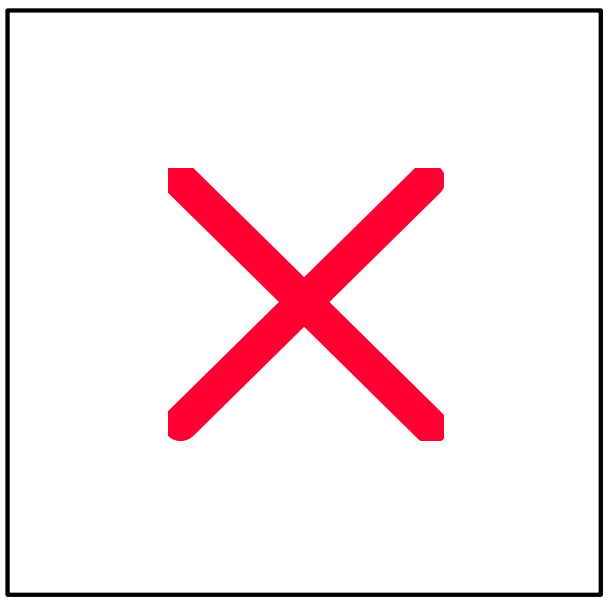
Metallographic Images of α–β Thermally Cycled Pu-Ingot

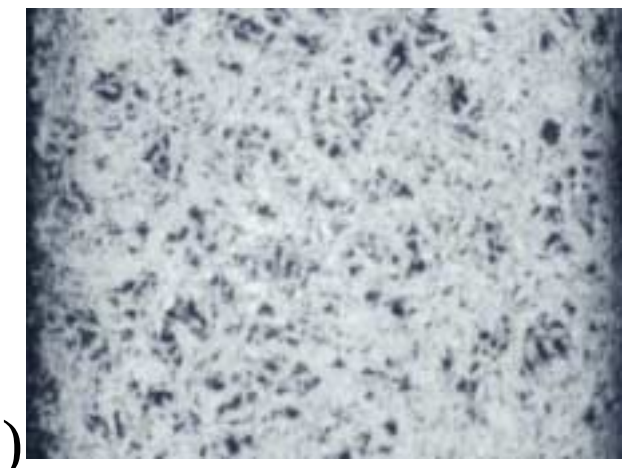


Top View (x10)



X-Section (x50)





As-Cast (x16)

α–β Results

- First Cycle:

  Plastic: 1.6% (1.1% ave)

  Elastic: 0.2% (0.3% ave)

  Total Strain: 1.8% (1.4% ave)

- After 6 cycles, no additional plastic strain:

  Total Plastic Strain: 2.02% (1.47% ave)

  0.071” increase in can diameter at waist (1.6%)

- Ingot Dimensions:

  Before: 0.751” thick, 4.358” diameter (Vol = 11.20 cu in)

  After: 0.803” thick, 4.338” diameter (Vol = 11.87 cu in)

  7% thickness increase, 0.45% diameter decrease, 6% volume increase

Constraining Pressures

- Yield Strengths:
  - α-Pu: 60,000 psi
  - β-Pu: 20,000 psi
- Calculated Constraining Pressures:
  - Based on yield strength of cylinder: 1100 psi
  - Based on measure strain: 1300 psi

$\Rightarrow$ Deformation of Pu ingot is likely due to preferential grain alignment during transformation.

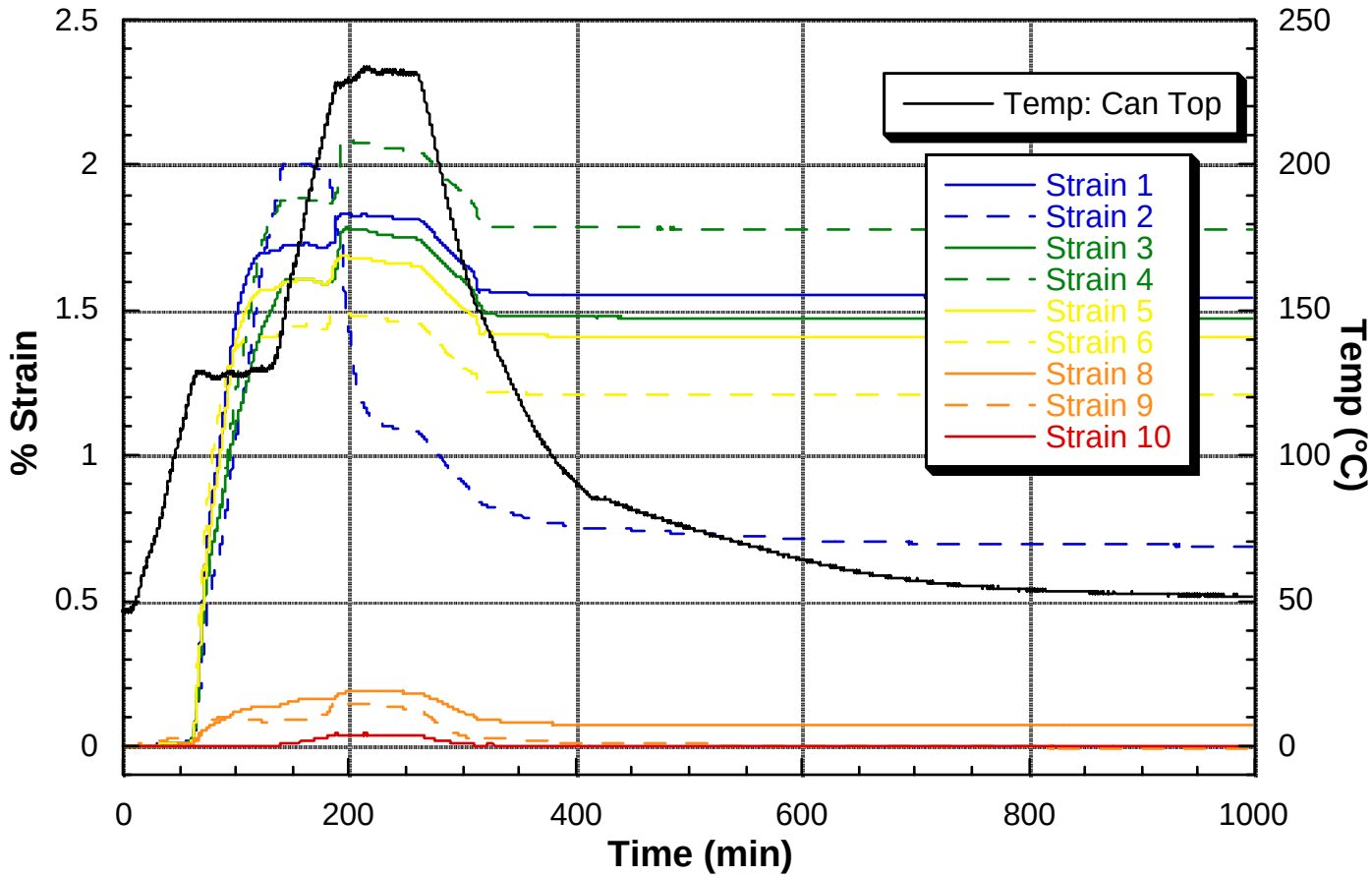
α–β Conclusions

- Additional plastic strain decreases with each cycle
- No additional plastic strain after 6 cycles
- Total Plastic Strain (6 cycles) = 1.47%
- ~1200 psi constraining pressure on Pu ingot
- Non-isotropic expansion of Pu ingot likely due to preferential grain alignment during transformation

β–γ Experimental Setup

- Same type can as used for α–β experiment
- 3.47 kg Pu ingot:
  - Diameter 0.012” < ID of can
  - 0.73” thick
  - ρ = 19.62 g/cc (ρ_{max} = 19.87 g/cc)
- 6 hoop, 1 far-field, 2 longitudinal strain gauges, 6 thermocouples
- thickness measured after each cycle
- resistively heated in tube furnace in Ar-atmosphere

Strain/Temp vs Time (1st Cycle)



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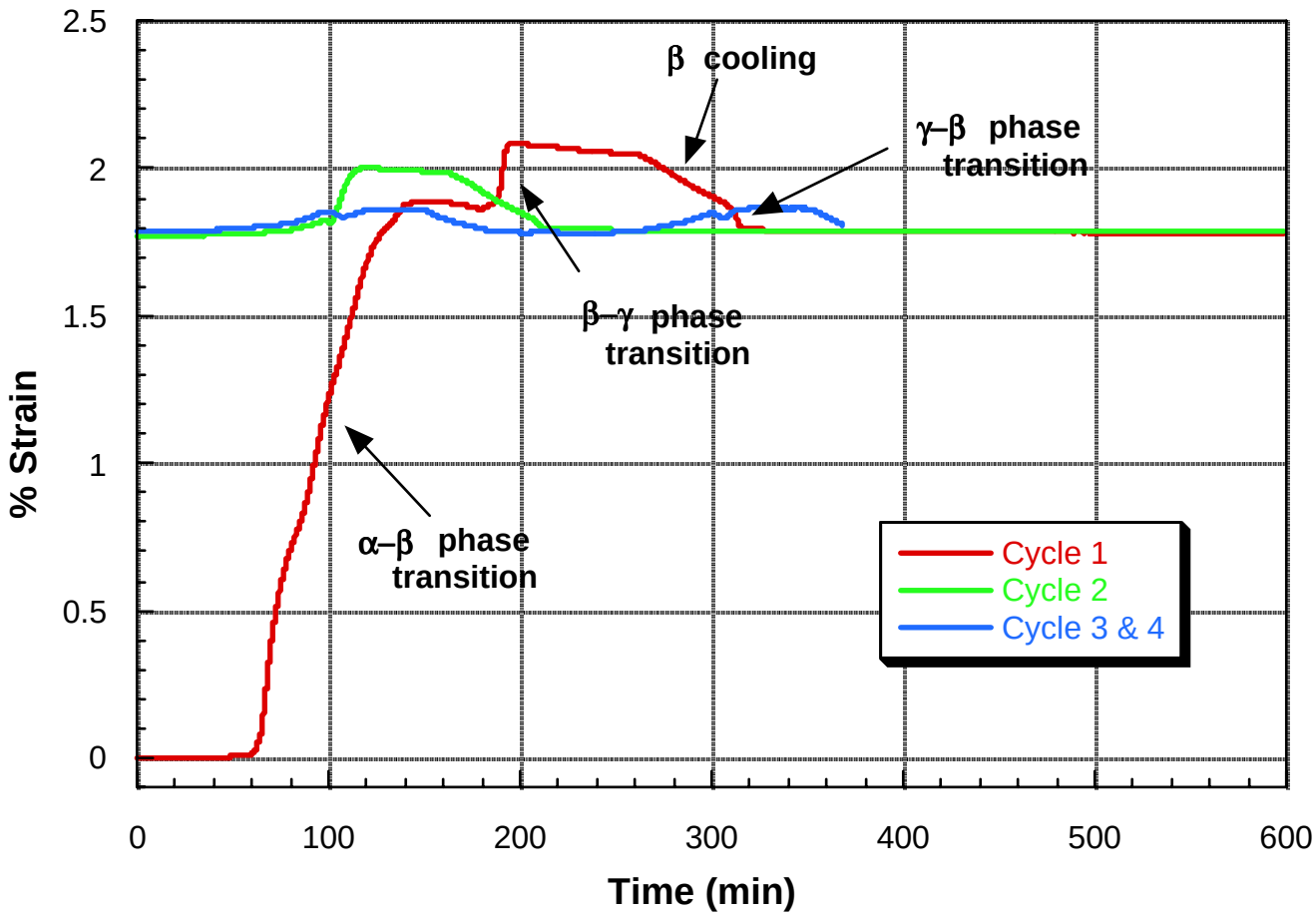
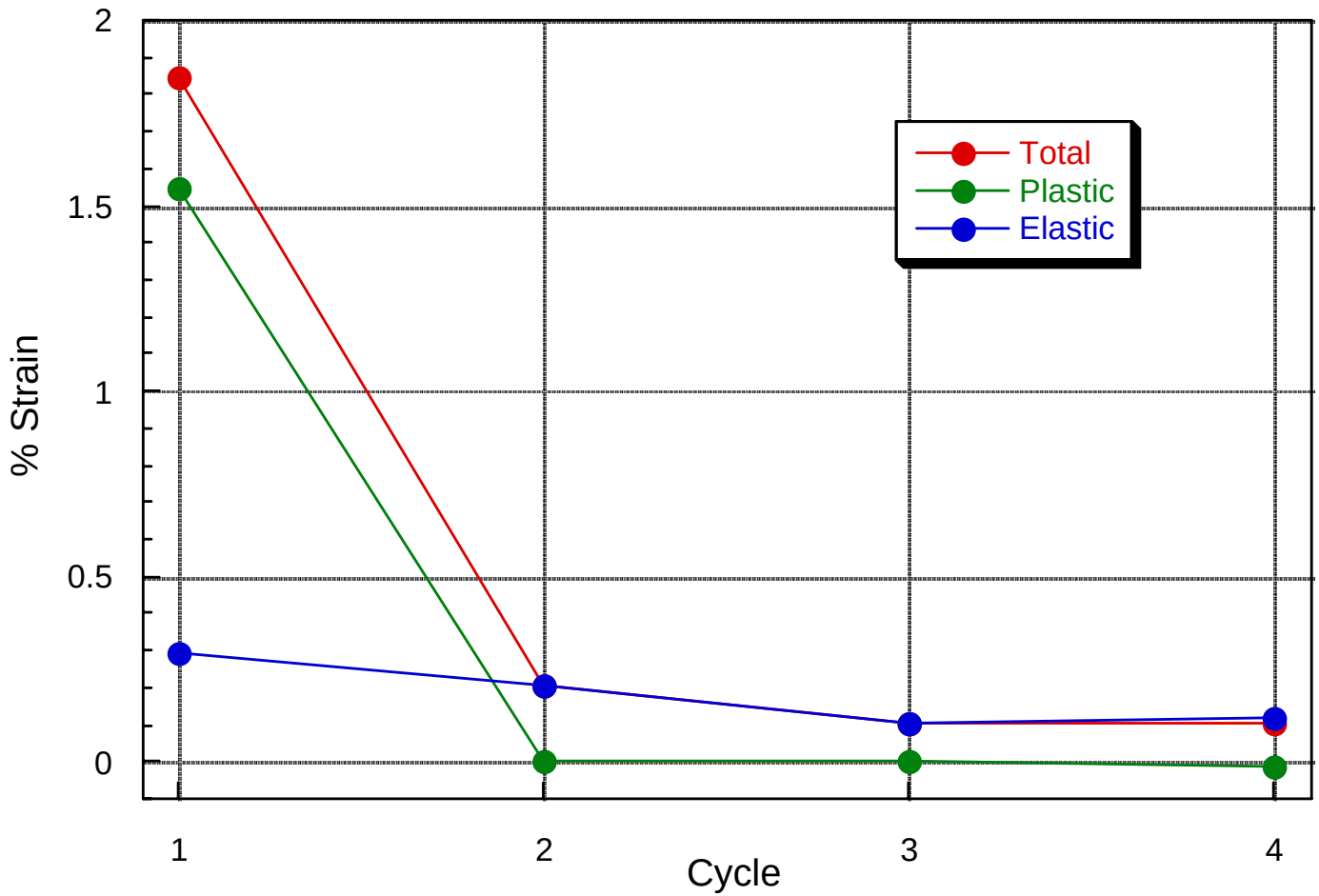
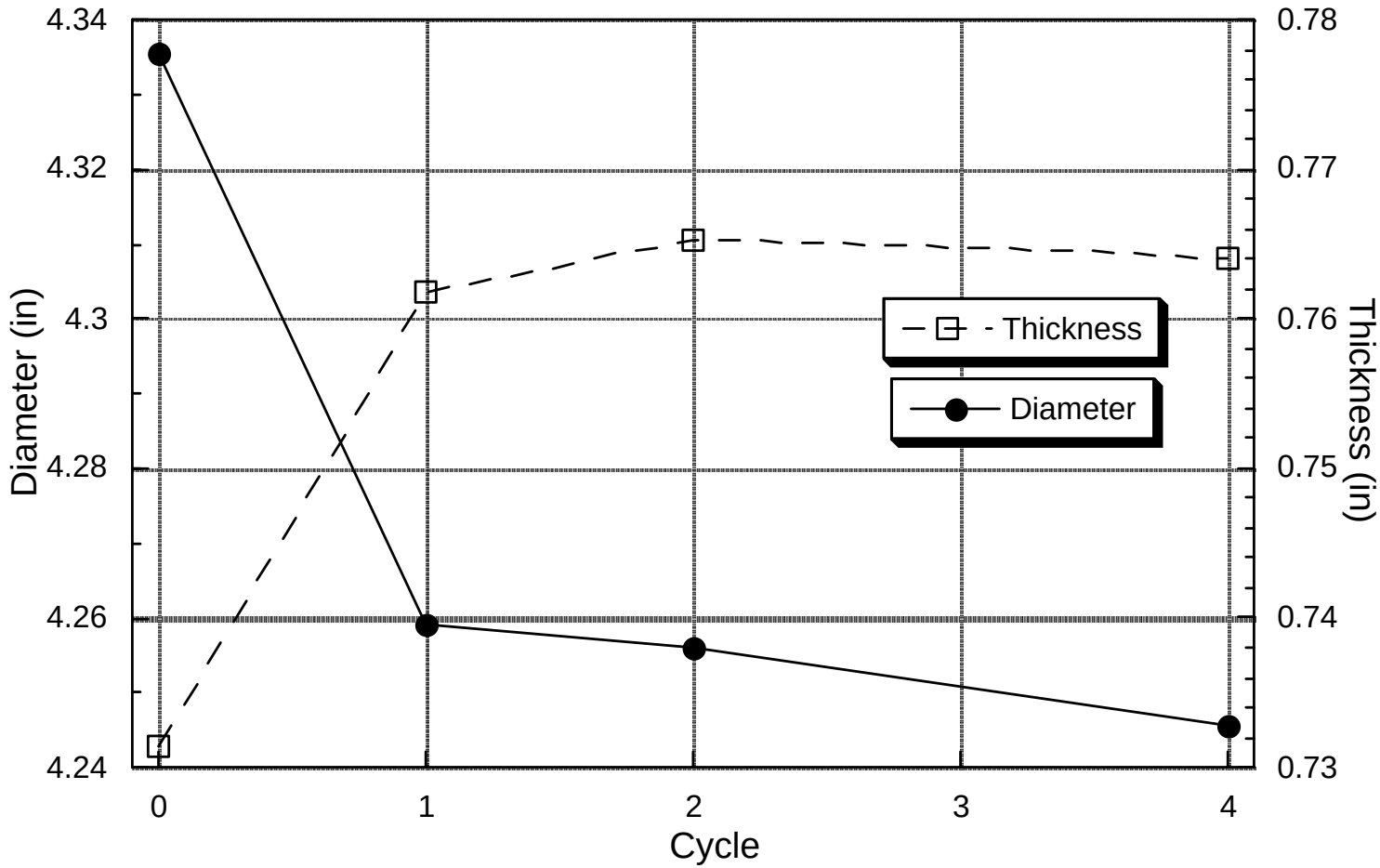
Strain vs Time



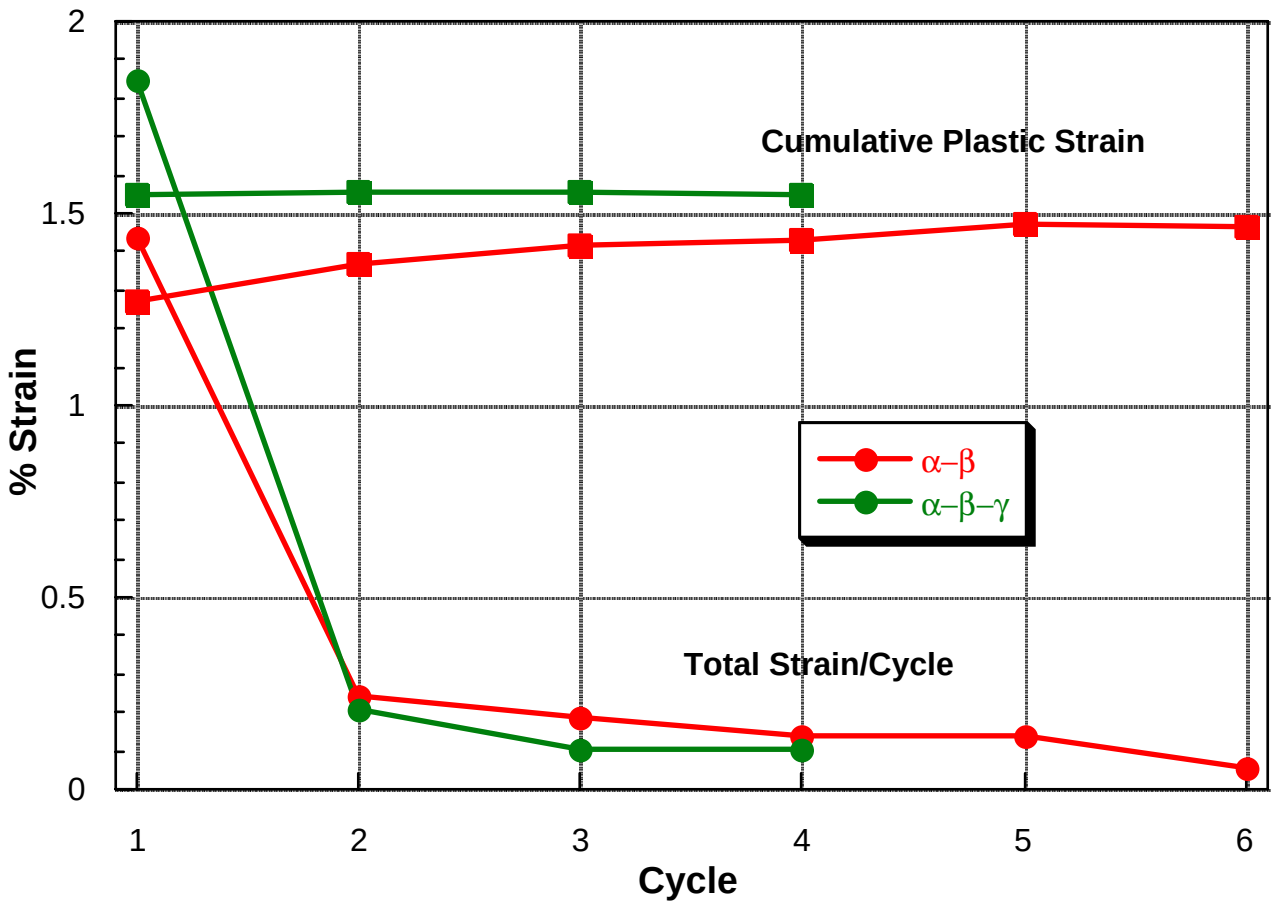
Ave Strain vs Cycle



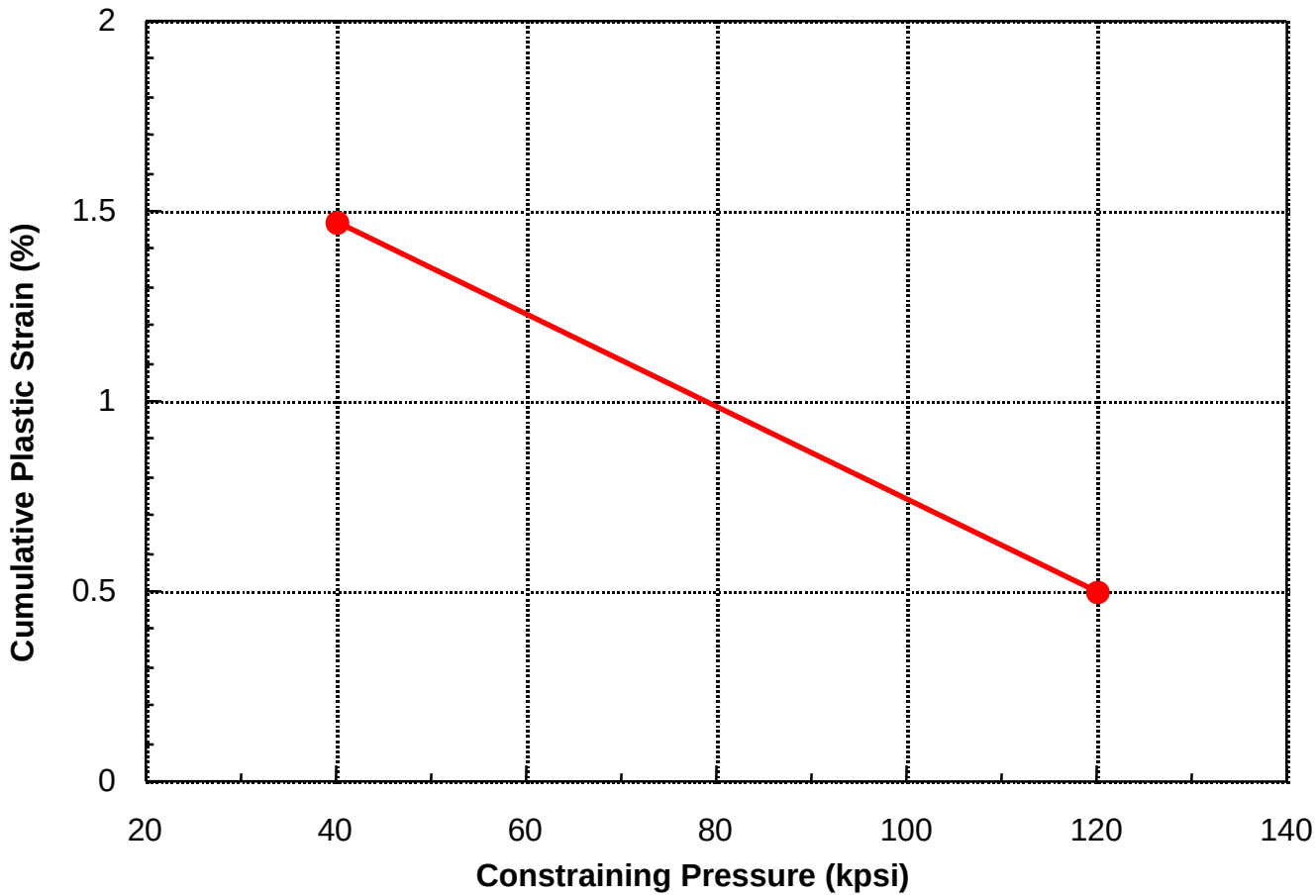
Ingot Thickness vs Cycle



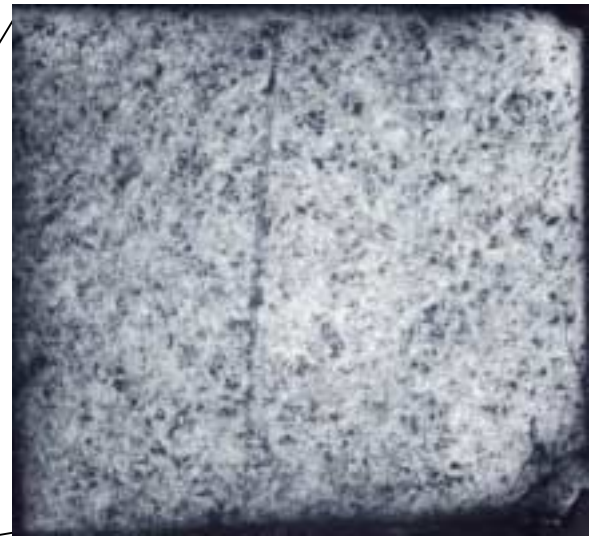
Ave Strain vs Cycle



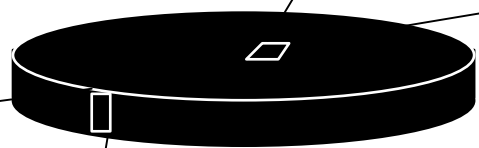
Plastic Strain vs Pressure



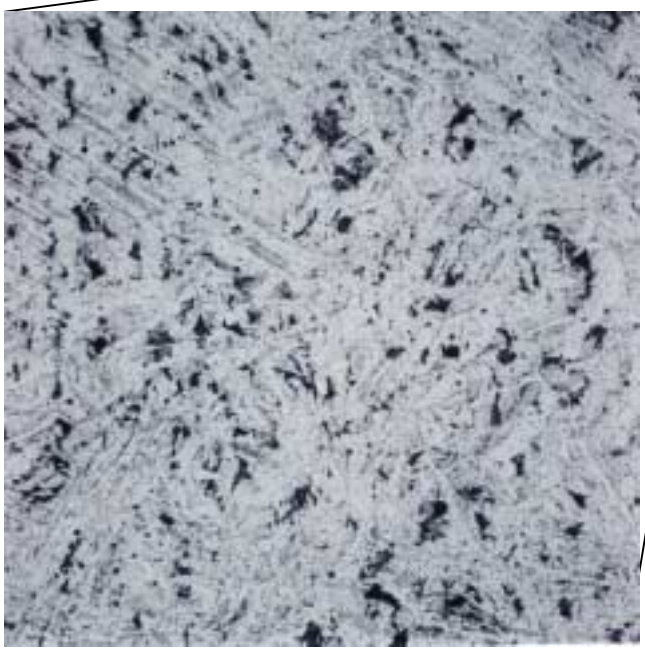
Metallographic Images of α–β–γ Thermally Cycled Pu-Ingot

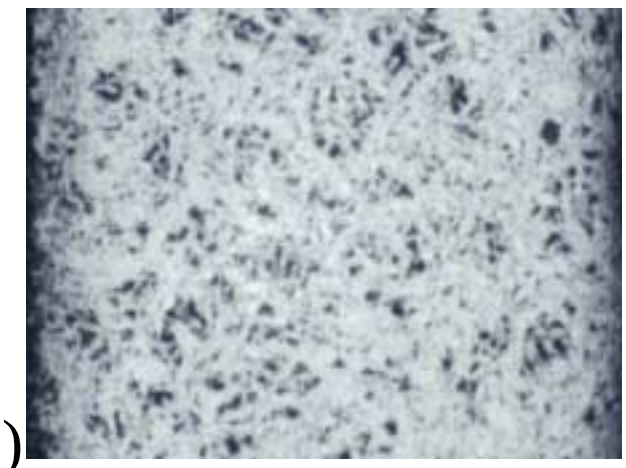


Top View (x16)



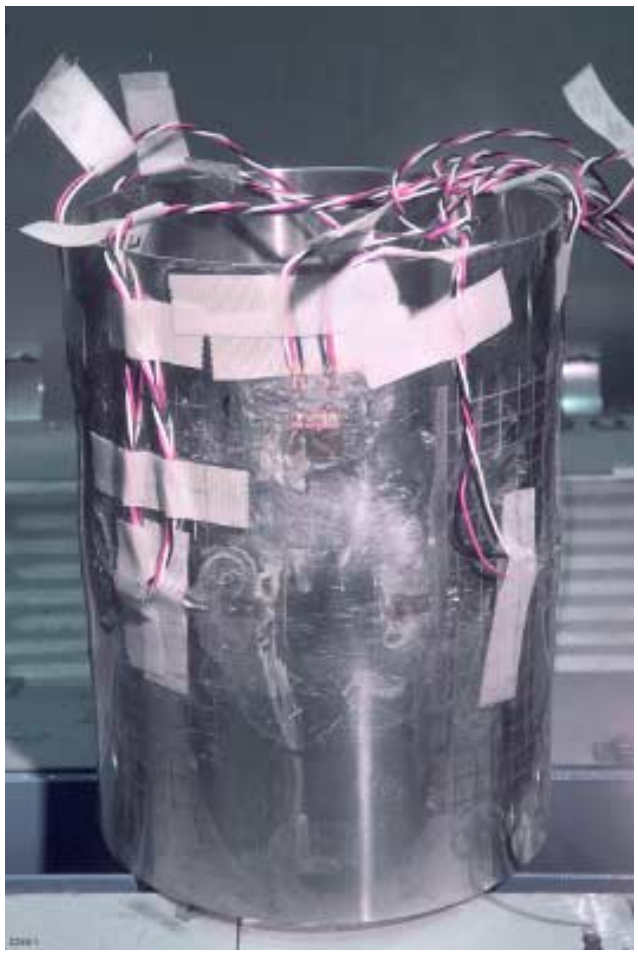
X-Section (x100)





As-Cast (x16)

Conclusions



- Max effective strain 4.2%; thermal cycling produces no additional plastic strain
- FEA analysis by SRS shows BNFL container compliant with ASME code
- No max. temp. requirement needed in storage standard to accommodate volume expansion from phase transitions.